IMPROVED HOLD-OFF CHARACTERISTICS OF GALLIUM ARSENIDE PHOTOCONDUCTIVE SWITCHES USED IN HIGH POWER APPLICATIONS*

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Abstract

Electron injection and the subsequent formation of a trap filled region leads to premature device failure in an opposed contact, EL2/carbon compensated GaAs photoconductive switch, made through the liquid encapsulated Czochralski process. Due to the electrostatic properties associated with a n^+/semi-insulating junction, the introduction of a n^+ region next to the cathode suppresses electron injection until higher bias. The doping level, length, and the thickness of the high n^+ region are some of the parameters that affect hold-off characteristics. Extending the length of the n^+ region well beyond the cathode does not increase the hold-off voltage but confines current flow to a narrow strip, which may trigger local heating burnout. Suppression of the effects of the EL2 traps at the n^+/SI interface also does not improve the hold-off characteristics.

Opposed contact switches, made from intrinsic GaAs have the characteristics of 'relaxation' semiconductors. The injection of minority carrier results in initial recombination and the formation of a large number of recombination regions may contribute to switching delays and jitters.

I. INTRODUCTION

Photoconductive semiconductor switches (PCSS), fabricated from low-doped, intrinsic or compensated semiconductor material, have many applications [1], one of which is the generation of ultra wide band (UWB) high power microwave (HPM) [2]. Because of its higher mobility and other material properties, Gallium Arsenide (GaAs) has advantages over silicon in applications where fast, repetitive switching action is required [3]. Compensated semi-insulating GaAs can be fabricated through different processes. Three of the better known

compensation processes are i) the deep donor and a shallow acceptor (DDSA) e.g. El2 with carbon, ii) shallow donor and a deep acceptor, SDDA, e.g.
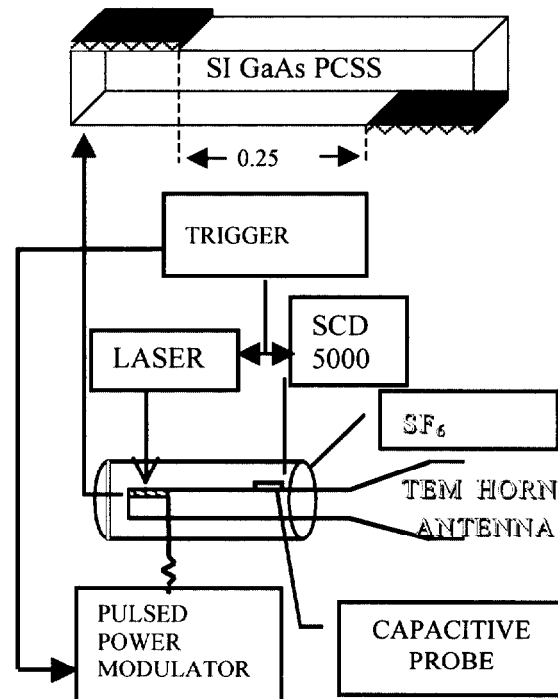

Figure 1. UMB radiation source setup and opposed contact PCSS.

silicon and chromium and, iii) deep donor and deep acceptor DDDA, e.g. EL2 with chromium. Furthermore, a compensated PCSS in the lock-on mode can also be triggered at much lower laser energy than would be normally required for generating electron-hole pairs in the material [4]. The behavior of a compensated material as a PCSS will depend on the process and will be different from that of a high resistivity intrinsic material where no compensation is required.

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14. ABSTRACT
Electron injection and the subsequent formation of a trap filled region leads to premature device failure in an opposed contact, EL2Icarbon compensated GaAs photoconductive switch, made through the liquid encapsulated Czochralski process. Due to the electrostatic properties associated with a n/semi-insulating junction, the introduction of a n+ region next to the cathode suppresses electron injection until higher bias. The doping level, length, and the thickness of the high n+ region are some of the parameters that affect hold-off characteristics. Extending the length of the n+ region well beyond the cathode does not increase the hold-off voltage but confines current flow to a narrow strip, which may trigger local heating burnout. Suppression of the effects of the EL2 traps at the n/SI interface also does not improve the hold-off characteristics. compensation processes are i) the deep donor and a shallow acceptor (DDSA) e.g. El2 with carbon, ii) shallow donor and a deep acceptor, SDDA, e.g. Opposed contact switches, made from intrinsic GaAs have the characteristics of relaxation semiconductors. The injection of minority carrier results in initial recombination and the formation of a large number of recombination regions may contribute to switching delays and jitters.

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In intrinsic semiconductors, the relaxation time of injected carriers is very short and is comparable to the lifetime of the minority carriers. The injection of minority carriers is initially followed by recombination and later carrier loss is compensated through the diffusion process [5]. In doped materials (relaxation time is comparatively greater than the carrier lifetime), however the injection of minority carriers is followed by augmentation to maintain charge neutrality and the diffusion process follows. It is therefore important to study and correlate the material parameters that affect the performance of the switches, specifically at high power operation. Surface flashover or the premature breakdown of the PCSS [6] is one such area. One reason for the early breakdown of DDSA type PCSSs is due to the formation of trap-filled regions that interfere with the filamentary nature of conduction [7]. The ionized EL2 sites act as electron traps in this material. Suppression of electron injection early on may thus allow for higher bias operation. The deposition of a n^+ layer next to the cathode could be one way of achieving this [8].

In this paper we present simulation results for the PCSS shown in Fig. 1 with the following objectives; i) characterization of the n^+ layer, ii) study of the effects of traps at the n+/SI interface and iii) comparison with an intrinsic opposed-contact GaAs PCSS with similar configuration.

II. MESH SETUP AND SIMULATION

Simulations were carried out using the SILVACO International software for semiconductor studies [9]. This is a comprehensive tool that unites semiconductor process, device and circuit simulations, and includes numerous models and parameters. In a 'mixed-mode' environment the device can be placed in a circuit and the effects of any changes in the device parameters on the overall circuit can be studied. In addition to the drift-diffusion model one can use the energy balance model to study such 'non-local' effects as velocity overshoot reduced energy dependent impact ionization where mobility and impact ionization become functions of local carrier temperature rather than the local electrical field. Finally, the code also has provisions to incorporate user defined functions through a C-interpreter.

Table I shows some of the device parameters used in the simulation. Details are provided elsewhere [7,8]. Besides known models, effects such as surface roughness, phonon scattering, and interaction between carriers and ions in the vicinity were also incorporated in the input. Some other parameters include field enhanced tunneling, effective contact resistivity, and parameters for subsurface conduction [10].

Table I

Distance between contacts	0.25 cm
Contact length	100 μm
Carbon doping	3×10^{15} atoms / cm^3
EL2 trap level	0.730 eV
Electron capture x-sections	4×10^{16} cm^2
Hole capture x-sections	2×10^{18} cm^2

III. COMPENSATED MATERIAL PCSS

The I-V characteristic of two opposed contact switches is shown in Fig. 2 (reproduced from reference 8). As can be seen, the device with the n^+ region has a better hold-off characteristic. This is primarily due to the junction properties associated with the n^+/SI interface [8]. The
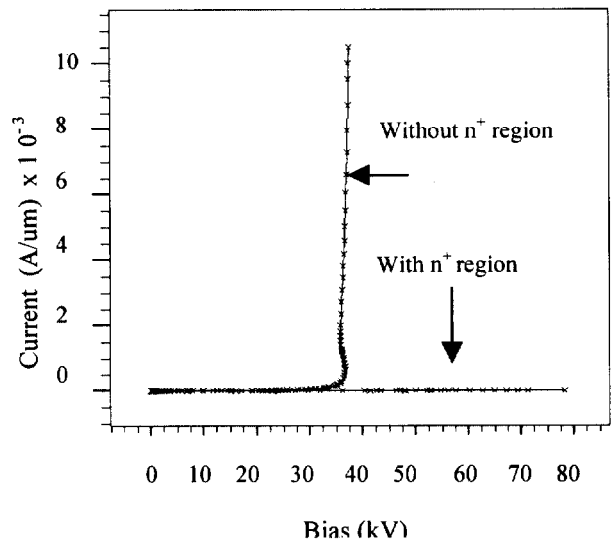

Figure 2. I-V characteristics for the switch with and without an n+ region next to the cathode.

length of the n^+ region extended about 100 μm beyond the cathode. Increasing the n^+ region all along the cathode surface did not bring about any significant increase in the hold-off characteristic. Rather the current was now confined to a narrow strip, as shown in Fig. 3. This increases the possibility of local heating and device burnout. Decreasing the n^+ region to half the device length brings about an improvement in the current flow distribution (not shown), but the best flow is for a length where the n^+ region is just covers the cathode contact. Increasing the peak doping for the n^+ region also for higher bias operations.

As reported elsewhere [8], the carrier distribution next to the n^+/SI interface shows a pn junction-like profile. This junction has the effect of shielding the cathode from the high substrate field. The p-region in the junction is
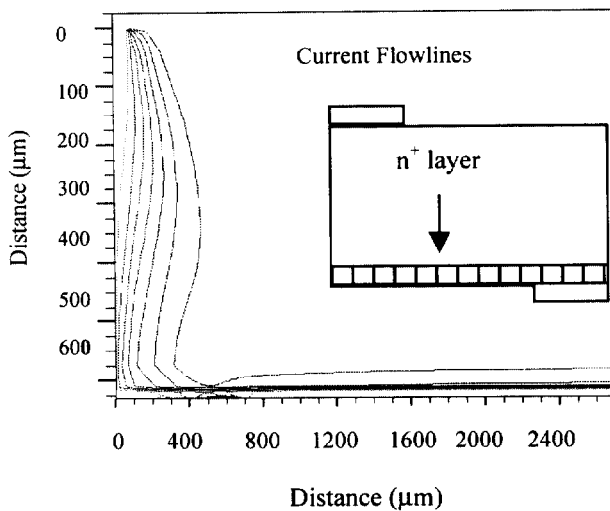
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Figure 3. Current flowline with n^+ region along the cathode surface.

formed when the EL2 trap levels are filled with captured electrons, leaving the region essentially carbon doped or a p-type GaAs. Doping the n^+ region with a background doping much above the EL2 donor level can also create a *pn* junction. It is of interest to see whether this junction has the same effect as the n+/SI interface.

Figure 4 is the I-V plot for a device where a p-type dopant of concentration 5×10^{15} /cm^3 was deposited as a background for the n-region. This has the effect of neutralizing the traps. As shown in Fig. 4, the I-V characteristic in this case is similar to the device without a n^+ region and there is no improvement in the hold-off characteristics. This is primarily due to the fact that
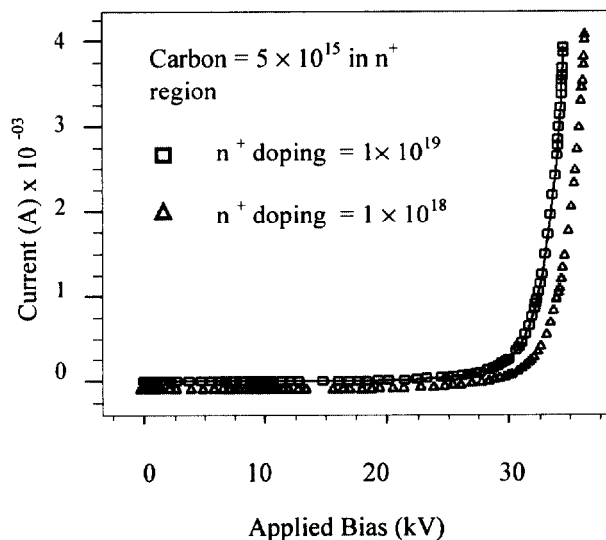

Figure 4. Response of the compensated PCSS without trapping effects at the n^+/SI region.

forward bias facilitates current injection of either polarity· with increasing bias. On the other hand for the n^+/Si junctions, the trapped electrons contribute to charge balance and are not free for conduction until at a high bias. Even by increasing the n^+ doping by an order of magnitude ($n = 1 \times 10^{19}$), the device hold-off voltage does not improve and breakdown is predicted at around 34 kV, which is the same as a device without the n-layer next to the cathode [7].

IV. INTRINSIC GaAs PCSS

As stated earlier switches that are made from intrinsic semiconductors will have higher recombination rates as compared to compensated material. Figure 5 shows the difference in the recombination rate in an intrinsic device and a PCSS during the charging phase.
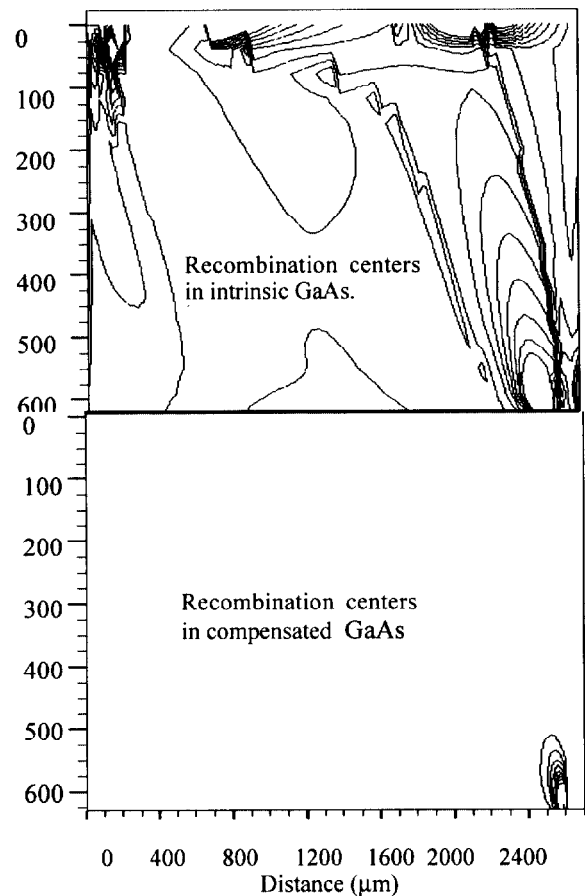

Figure 5. Recombination sites in intrinsic and compensated materials.

Both the plots are for the case the switch is charged to 20 kV. A large recombination in the intrinsic material early on adversely affects the initial current, as shown in Fig. 6. Compensated materials, on the other hand, behave much like lifetime semiconductors, where the Debye (L_D) length reduces to the screening length L_S [5], given as

$$L_S = \frac{L_D}{\sqrt{1 + \dfrac{N_t}{n_0}}}$$

where N_t and n_0 are the trap and equilibrium electron concentration respectively.
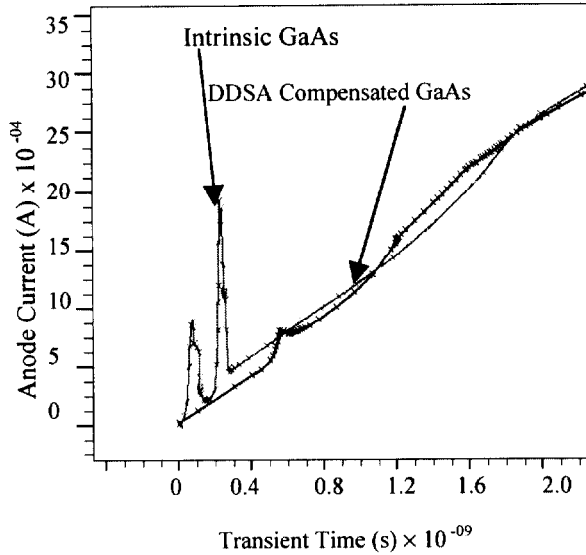

Figure 6. Initial response of intrinsic and compensated PCSS.

V. SUMMARY AND CONCLUSION

The response of photoconductive switches made from GaAs during high power operation depends on the material properties and the operational state of the switches. The response depends on whether the switch is made from very low doped or intrinsic material or from compensation mechanism. It also depends on the operational mode, i.e whether it is in the linear or the lock-on mode, or if it is in the pulse charging (off) state or in the conduction (on) state. For devices made through the compensation of a deep donor and a shallow acceptor, such as EL2 and carbon, the deposition of a n^+ layer next to the cathode and the resulting n^+/SI interface electrostatic characteristics bring about a suppression of electron injection from the cathode. Increasing the doping level increases the hold-off voltage, while the length of the device beyond the cathode length does not improve the device characteristics. Also, the creation of a *pn* junction with a p-type background doping in the n-layer does not have the same effect as a *pn* junction due to n^+/SI interface interaction.

For intrinsic materials, even though the hold-off voltage is high due to the 'relaxation' nature of the material, the current transport characteristic is different. A large recombination rate following charge injection in these devices affect both the charging voltage and the response

of the device during the switching action that may lead to jitter and delay in the pulse.

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